CHEMICAL MILLING PROCESS AND SOLUTION FOR CAST TITANIUM ALLOYS

BACKGROUND OF THE INVENTION

The present invention relates to a process for chemically milling parts formed from a metallic material, in particular, a titanium alloy, and to a milling solution used to mill such parts.

Chemical milling of castings formed from titanium alloys such as Ti 6-2-4-2 (a titanium based alloy containing 6 wt% aluminum, 2 wt% tin, 4 wt% zirconium, 2 wt% molybdenum, and the balance essentially titanium) generally results in unacceptable intergranular attack which results in an approximate 10X debit in low cycle fatigue life and a corresponding decrease in high cycle fatigue capability. This impacts fatigue limited parts formed from chemically milled titanium alloys such as stator vanes and casings on jet engines.

Thus, there is a need for a process and a milling solution which allows desired metal removal without the occurrence of significant intergranular attack.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide a chemical milling process for parts which avoids the occurrence of significant intergranular attack.

It is a further object of the present invention to provide an improved chemical milling solution for carrying out the aforementioned chemical milling process.

The foregoing objects are attained by the chemical milling process of the present invention and the novel chemical milling solution of the present invention.

In accordance with the present invention, a process for chemically milling a metallic part without causing significant

intergranular attack broadly comprises the steps of: providing a milling solution containing nitric acid, hydrofluoric acid, dissolved titanium, a wetting agent, and water; maintaining the milling solution at a temperature in the range of from about 110°F to 130°F; and immersing said part formed from a titanium alloy in the milling solution for a time sufficient to mill a desired depth on at least one surface of the part.

In accordance with the present invention, a solution for chemically milling a metal part formed without causing significant intergranular attack is formed from nitric acid, hydrofluoric acid, dissolved titanium, a wetting agent, and the balance water.

Other details of the chemical milling process and the chemical milling solution of the present invention, as well as other objects and advantages attendant thereto, are set forth in the following detailed description and the accompanying drawings wherein like reference numerals depict like elements.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1 - 4 are photomicrographs showing the intergranular attack results of two trials using chemical milling solutions in accordance with the present invention to remove 0.020" per side at a magnification of 200X.

FIGS. 5 and 6 are photomicrographs showing the intergranular attack results of a titanium alloy part chemically milled in a standard titanium milling solution at 110°F with removal being 0.020" per side at a magnification of 200X.

FIGS. 7 and 8 are photomicrographs showing the intergranular attack results of a titanium alloy part chemically milled in a standard titanium milling solution at 125°F with removal being 0.020" per side at a magnification of 200X.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

Various parts used on turbine engines are cast from metallic titanium based alloys. A common metallic material used for these parts is a titanium alloy designated Ti 6-2-4-2. These cast parts need to be chemically milled to remove the alpha case which results from the mold to metal reaction or a high temperature thermal exposure. Typically, up to about 0.020″ per side is removed to eliminate the alpha case. This removal operation typically involves immersing the cast metal part into a chemical milling solution for a time period sufficient to remove a desired depth of material from the part.

In accordance with the present invention, a chemical milling solution for milling metal parts, preferably formed from titanium based alloys, without producing significant intergranular attack has been designed. The chemical milling solution contains nitric acid, hydrofluoric acid, dissolved titanium, a wetting agent, and the balance water. The wetting agent preferably is present in an amount sufficient to create a surface tension in the range of about 30 to 36 dynes/cm^2. The nitric acid and hydrofluoric acid constituents are present in a HNO_3/HF ratio in the range of from about 1:1 to about 2:1, preferably from about 1:1 to about 1.5:1, and most preferably about 1:1. During use, the solution should be maintained at a temperature in the range of from about $110^{\circ}F$ to about $130^{\circ}F$, preferably from about $115^{\circ}F$ to about $125^{\circ}F$. The dissolved titanium in the solution should be present in an amount less than about 2.5 oz./gal.

When the HNO_3/HF ratio is in the range of 1:1 to 2:1 and the solution temperature is in the range of from about $110^{\circ}F$ to about $130^{\circ}F$, the dissolved titanium may be present in an amount up to about 0.5 oz./gal. When the HNO_3/HF ratio is in the range of from about 1:1 to about 1.5:1 and the solution temperature is in the range of from about $115^{\circ}F$ to about $125^{\circ}F$, the dissolved

titanium may be present in an amount up to about 1.5 oz./gal. When the HNO_3/HF ratio is about 1:1 and the solution temperature is in the range of from about 115°F to about 125°F, the dissolved titanium may be present in an amount up to about 2.5 oz./gal. This information is summarized in Table I.

TABLE I

	Surface Tension (dynes/cm^2)	HNO_3/HF Ratio	Temperature (°F)	Dissolved Ti (oz/gal)
Solution Limits	30 - 36	1.0 - 2.0	110 - 130	0.0 - 0.5
Solution Limits	30 - 36	1.0 - 1.5	115 - 125	0.5 - 1.5
Solution Limits	30 - 36	~1.0	115 - 125	1.5 - 2.5

While it is preferred to use a fluorosurfactant, such as FC95 manufactured by 3M Corp., as the wetting agent, other surfactants known in the art may be used provided that they keep the surface tension of the solution within the desired range.

If desired, additions may be made to the milling solutions so as to provide a beneficial effect on surface finish. These additions may comprise a material selected from the group consisting of urea, dissolved palladium metal, precious metals other than silver, and mixtures thereof. When urea is used, it may be present in an amount greater than about 20 grams/liter. When dissolved palladium is used, it may be present in an amount greater than about 10 ppm, preferably in an amount in the range of from about 50 ppm to about 200 ppm.

Two trials were conducted to demonstrate the significant reduction in intergranular attack which could be obtained through the use of chemical milling solutions in accordance with the present invention. The first trial was carried out using a milling solution containing 72 ml. (7.2 vol%) (70% conc.) nitric acid, 35 ml. (3.5 vol%) (70% conc.) hydrofluoric acid, 3 grams of dissolved titanium, surfactant in an amount sufficient to

obtain a surface tension of 36 dynes/cm^2, and the balance water. The second trial was carried out using a solution which contained 72 ml. (7.2 vol%)(70% conc.) nitric acid, 48 ml. (4.8 vol%) (70% conc.) hydrofluoric acid, 3 grams of dissolved titanium, surfactant in an amount sufficient to obtain a surface tension of 36 dynes/cm^2, and the balance water. During each trial, the chemical milling solution was maintained at a temperature of 125°F and a casting formed from a titanium 6-2-4-2 alloy was immersed in the solution. Photographs documenting the chemically milled surface from these trials are presented in FIGS. 1 - 4. The photomicrographs are a cross section through the chemically milled castings. The photomicrographs document the worst case intergranular attack produced by milling the castings in the trial solutions, which is 0.00015″. By comparing the photomicrographs of FIGS. 1 - 4 with the photomicrographs of FIGS. 5 - 8, which show the results of a similar cast part which was chemically milled in a standard titanium solution at 110°F and 125°F, it can be seen that the intergranular attack in FIGS. 1 - 4 is less than that which occurred when chemically milling the same type of castings in standard titanium solutions. FIGS. 5 and 6 show the worst intergranular attack to be 0.001″ and FIGS. 7 and 8 show the worst intergranular attack to be 0.0005″.

The results of the foregoing trials demonstrate that Ti 6-2-4-2 cast parts can be chemically milled with minimal intergranular attack. The intergranular attack for the solutions examined is less than 0.0002″, the critical value of intergranular attack for full fatigue capability.

Milling solutions with a higher volume percent of acid, which maintain a HNO_3/HF ratio within the aforementioned ranges, and a low level of dissolved titanium are also workable. For example, such a solution could have 10.5 vol% nitric acid and 7.0 vol% hydrofluoric acid. The remaining ingredients in the

solution, namely, the dissolved titanium, the surfactant, and the water are within the ranges described hereinbefore.

In one embodiment of a chemical milling solution, for one liter of solution, the solution contains 7.2 vol% nitric acid, 4.1 vol% hydrofluoric acid, up to 1.5 grams of dissolved titanium, a surfactant as required to reach a surface tension of 33 dynes/cm^2, and the balance water.

In yet another embodiment of a chemical milling solution, for one liter of solution, the solution contains 7.2 vol% of nitric acid, 4.8 vol% of hydrofluoric acid, dissolved titanium in an amount up to about 0.05 grams, a surfactant as required to reach a surface tension of about 36 dynes/cm^2, and the balance water.

In accordance with the process of the present invention, a milling solution containing nitric acid, hydrofluoric acid, a surfactant, dissolved titanium and water is prepared. The solution is then heated to a temperature in the range of from about 110°F to about 130°F, preferably from about 115°F to 125°F, and maintained at the temperature. The part formed from the titanium based alloy is then immersed in the milling solution, either fully or partially, for a time sufficient to remove a desired depth of material from at least one surface of the part.

While the milling solutions of the present invention have been found useful to chemically mill parts formed from Ti 6-2-4-2, the solutions could be used to mill parts formed from other titanium based alloys and other metal alloys. The milling solution of the present invention has been shown to have a beneficial effect on the surface finish of cast Ti 6-4 alloys (a titanium based alloy containing 6 wt% aluminum, 4 wt% vanadium, and the balance essentially titanium).

It is apparent that there has been provided in accordance with the present invention a chemical milling process and solution for cast titanium parts which fully satisfies the

objects, means, and advantages set forth hereinbefore. While the present invention has been described in the context of specific embodiments thereof, other alternatives, modifications, and variations will become apparent to those skilled in the art having read the foregoing description. Therefore, it is intended to embrace those alternatives, modifications, and variations as fall within the broad scope of the appended claims.